



US009263962B2

(12) **United States Patent**  
**Yang et al.**

(10) **Patent No.:** **US 9,263,962 B2**  
(45) **Date of Patent:** **Feb. 16, 2016**

(54) **POWER CONVERSION SYSTEM AND METHOD**

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(\*) Notice: Subject to any disclaimer, the term of this  
patent is extended or adjusted under 35  
U.S.C. 154(b) by 6 days.

(21) Appl. No.: **14/449,181**

(22) Filed: **Aug. 1, 2014**

(65) **Prior Publication Data**

US 2015/0035284 A1 Feb. 5, 2015

(30) **Foreign Application Priority Data**

Aug. 2, 2013 (CN) ..... 2013 1 0334563

(51) **Int. Cl.**  
**F03D 9/00** (2006.01)  
**H02P 9/04** (2006.01)  
**H02M 5/42** (2006.01)  
**H02M 5/45** (2006.01)

(Continued)

(52) **U.S. Cl.**  
CPC . **H02M 5/42** (2013.01); **H02M 1/12** (2013.01);  
**H02M 7/5395** (2013.01); **H02M 2001/007**  
(2013.01); **H02M 2001/0074** (2013.01); **H02M**  
**2001/0077** (2013.01); **Y10T 307/707** (2015.04)

(58) **Field of Classification Search**

USPC ..... 290/44, 55; 363/37  
See application file for complete search history.

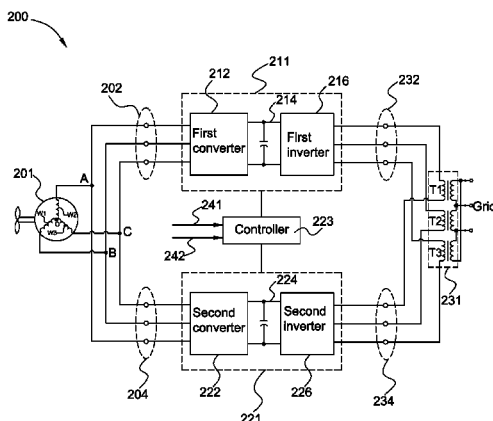
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(57) **ABSTRACT**

An exemplary power conversion system includes a first power conversion module, a second power conversion module, and a controller. The first power conversion module includes a first source side converter, a first load side converter, and a first DC link coupled between the first source side converter and the second load side converter. The second power conversion module includes a second source side converter, a second load side converter, and a second DC link coupled between the second source side converter and the second load side converter. The controller is configured to generate a number of switching signals according to a circuit structure of the power source module or a circuit structure of the load module. The switching signals are provided to the first power conversion module and the second power conversion module to balance a first DC link voltage and a second DC link voltage.

**20 Claims, 13 Drawing Sheets**



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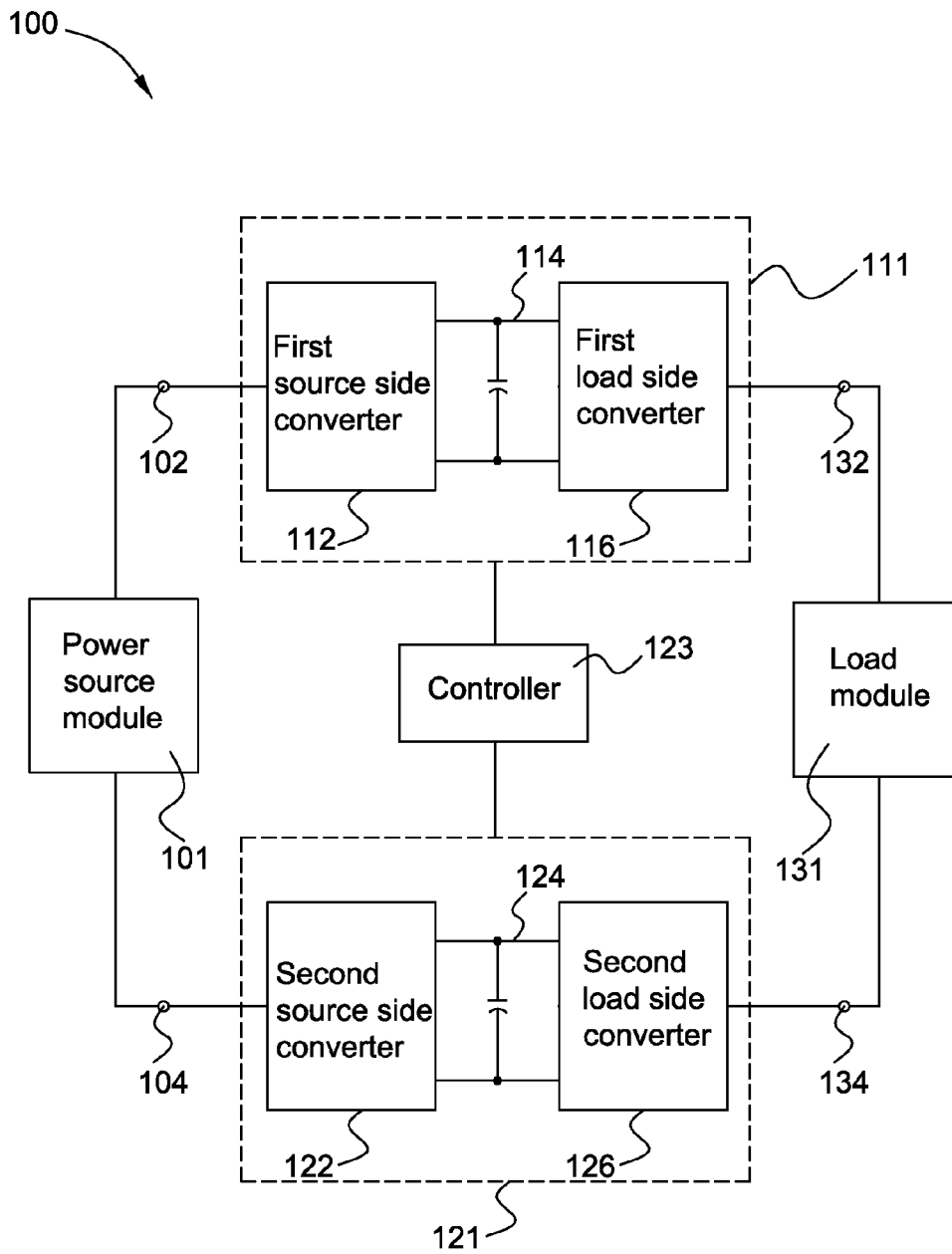


FIG. 1

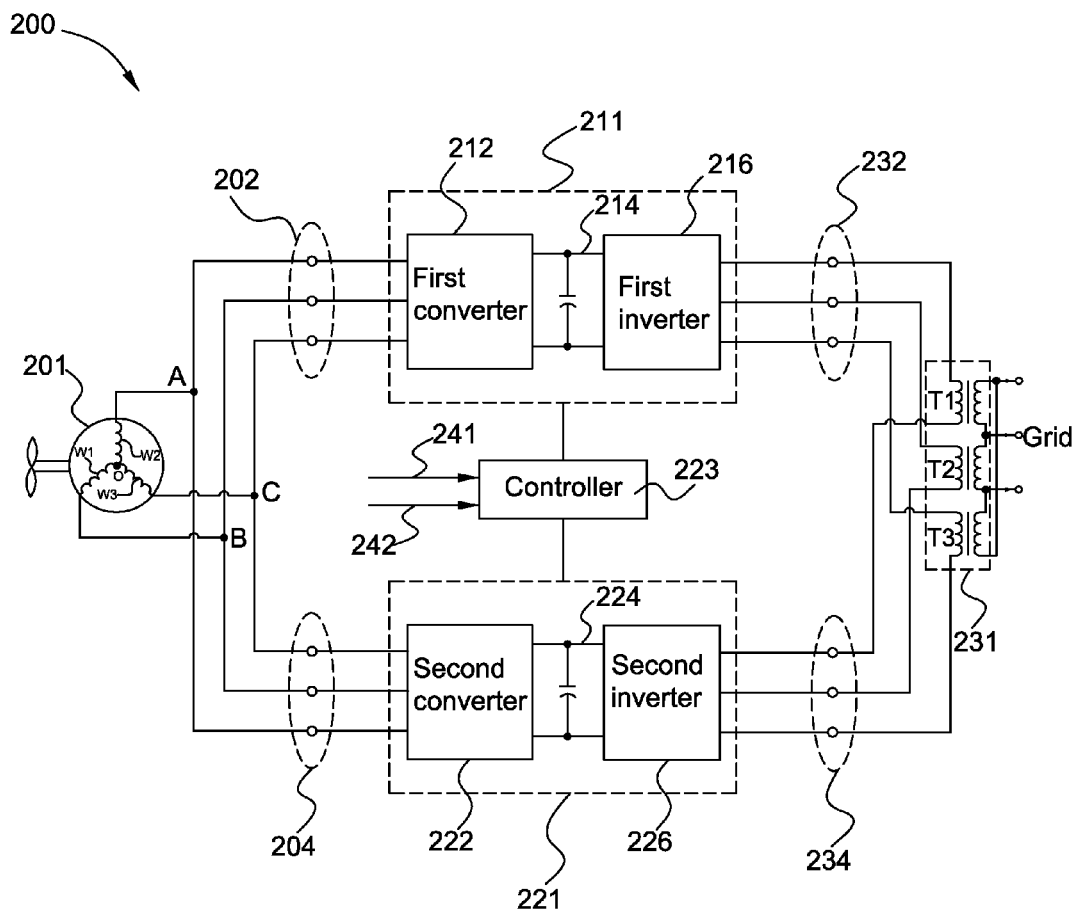


FIG. 2

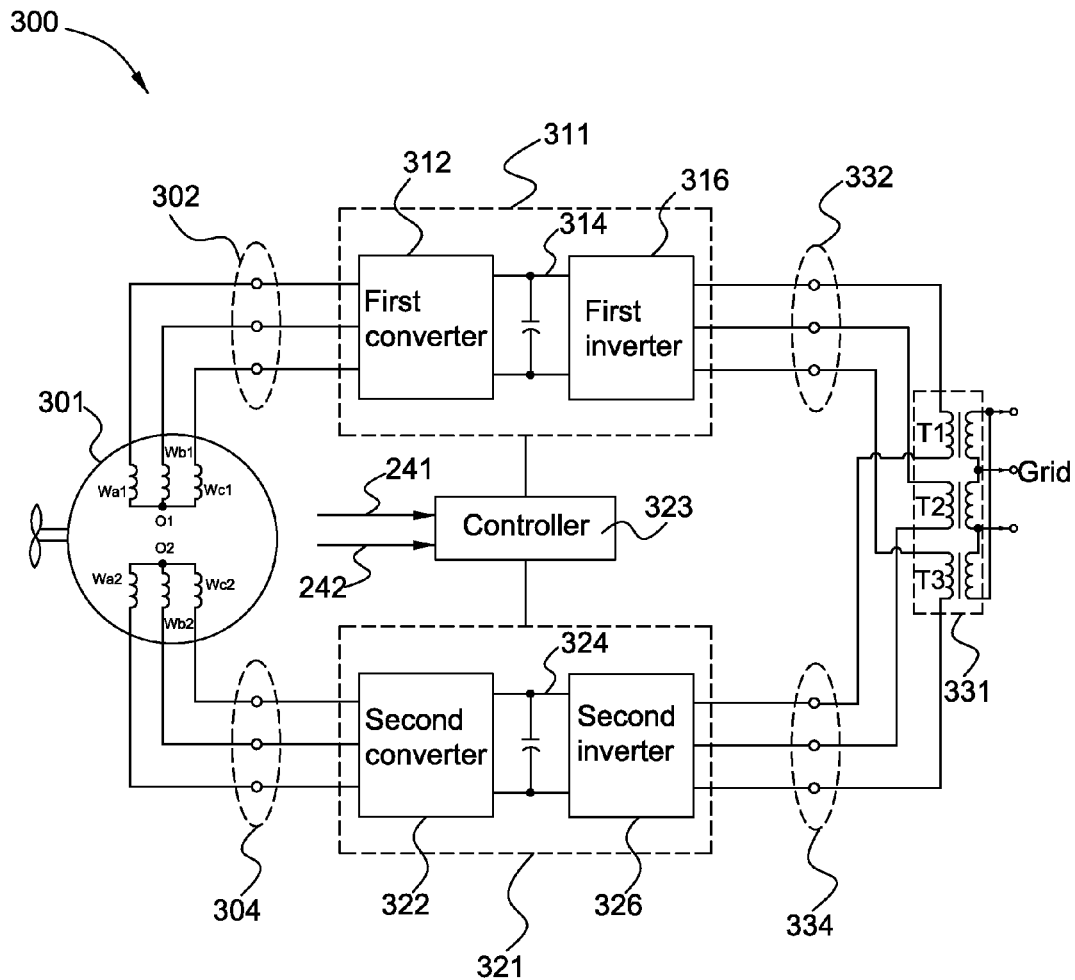


FIG. 3

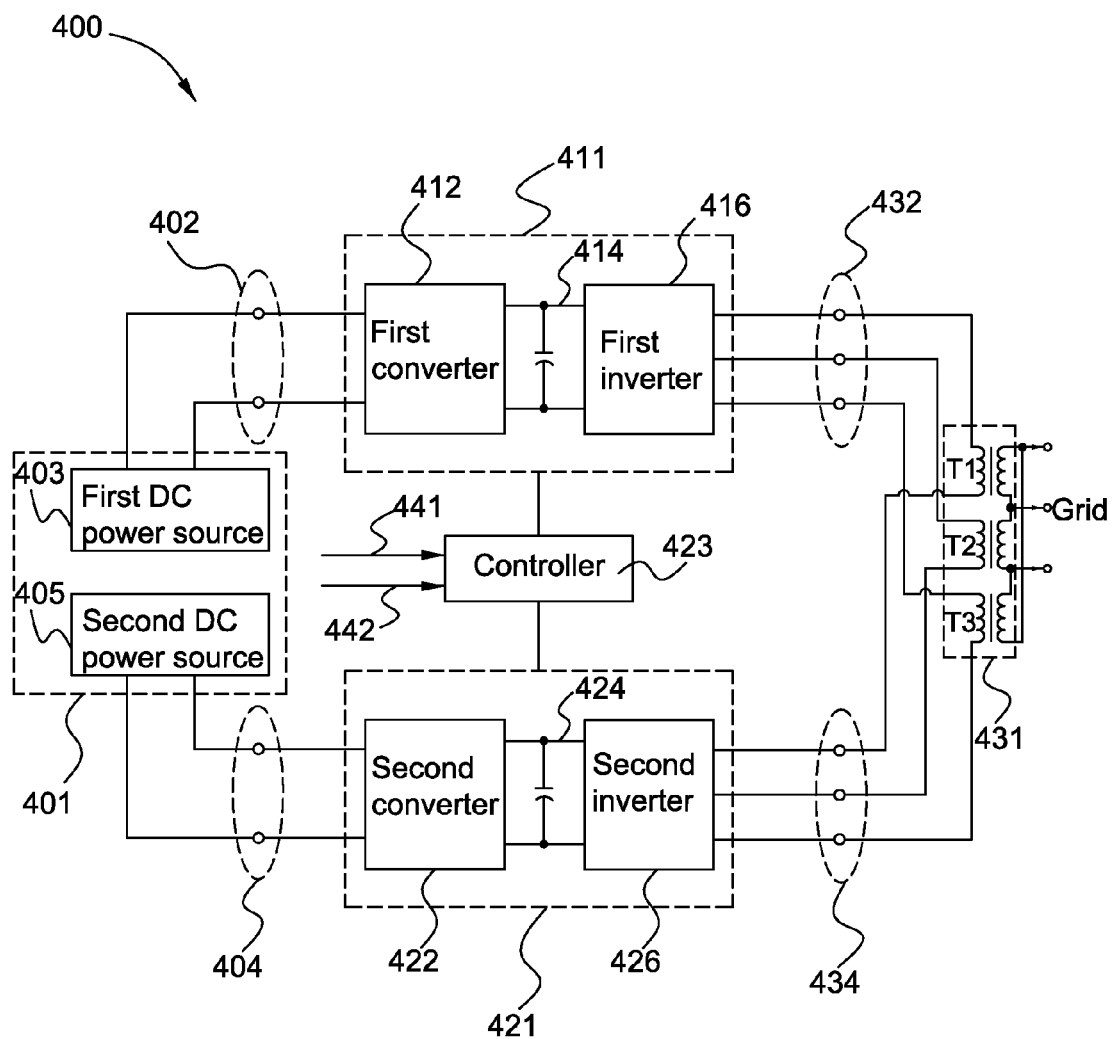


FIG. 4

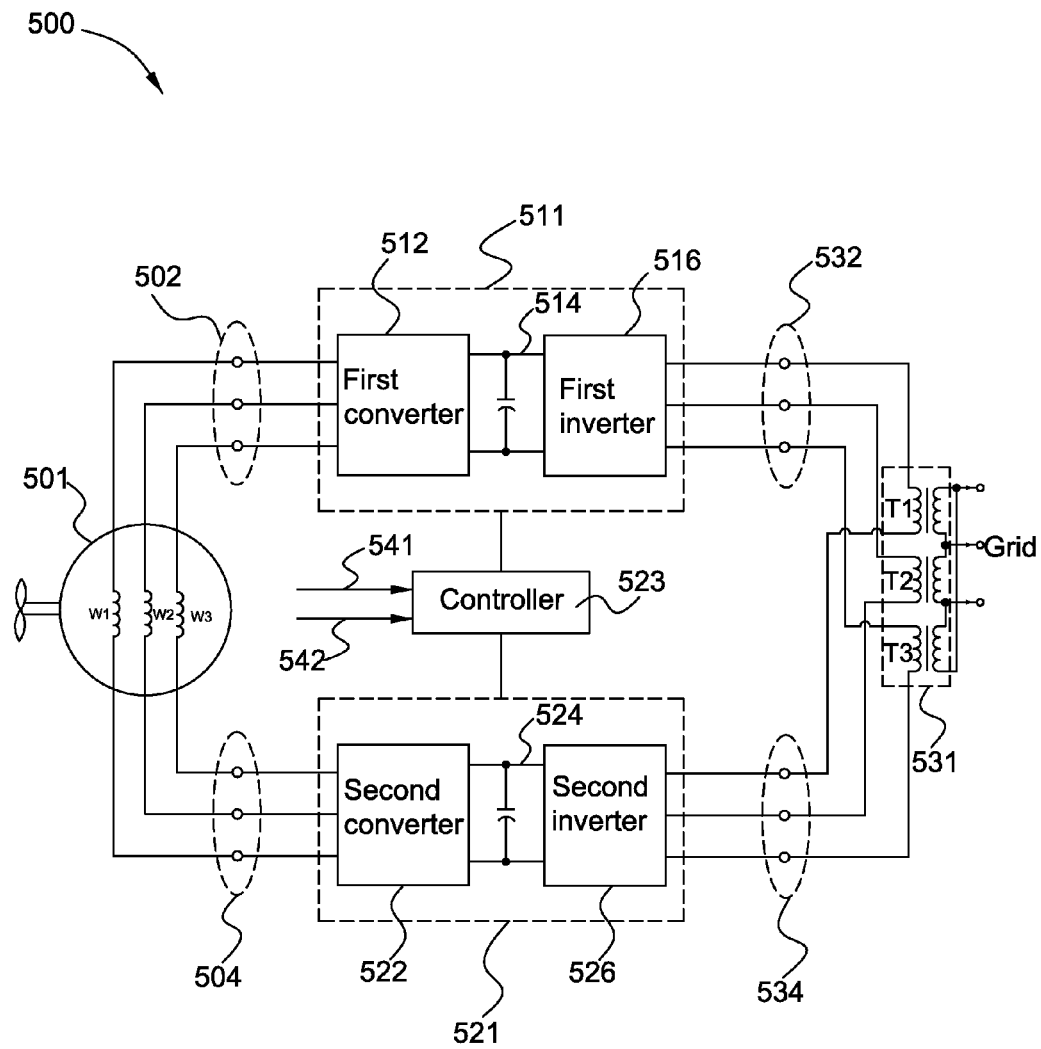


FIG. 5

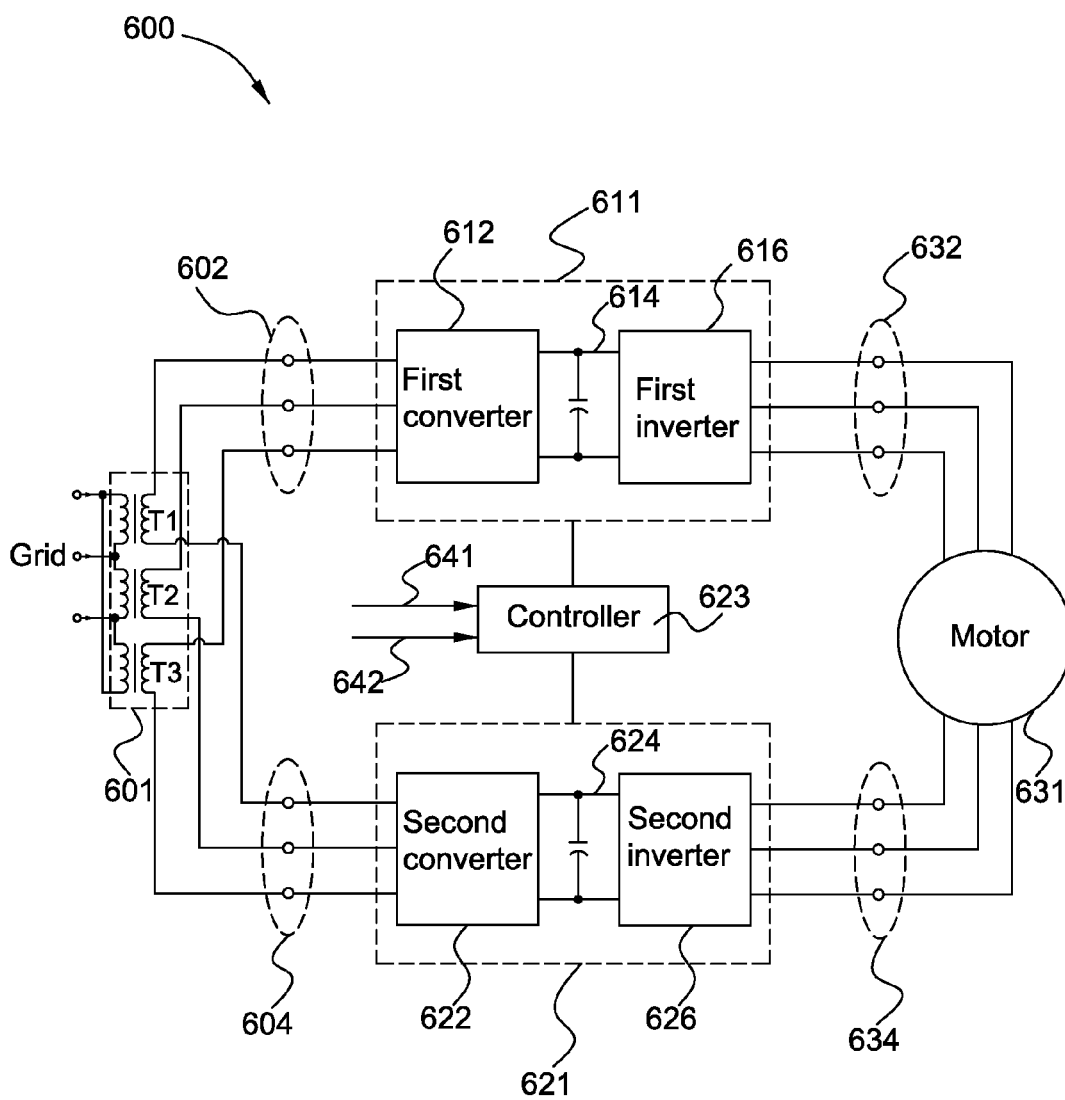


FIG. 6



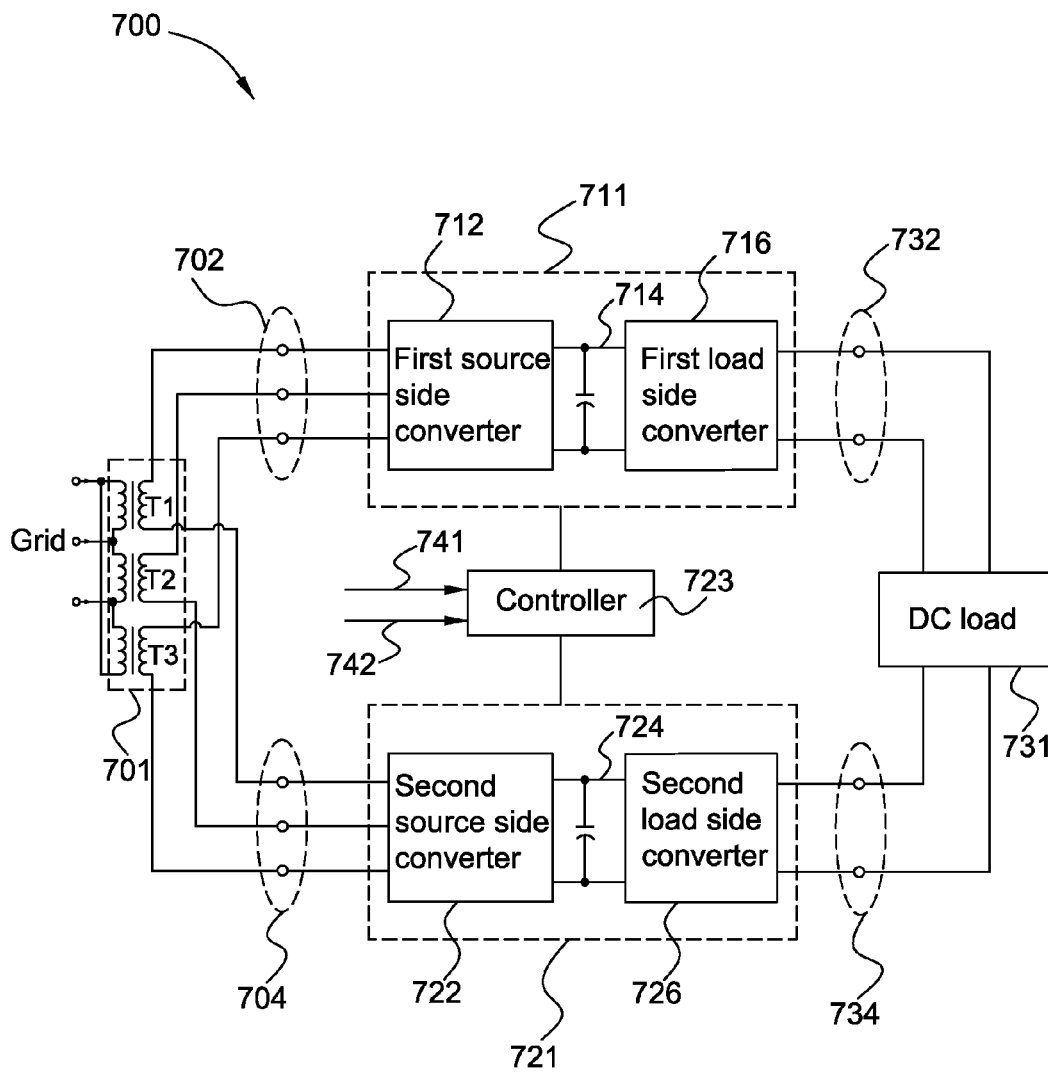


FIG. 7

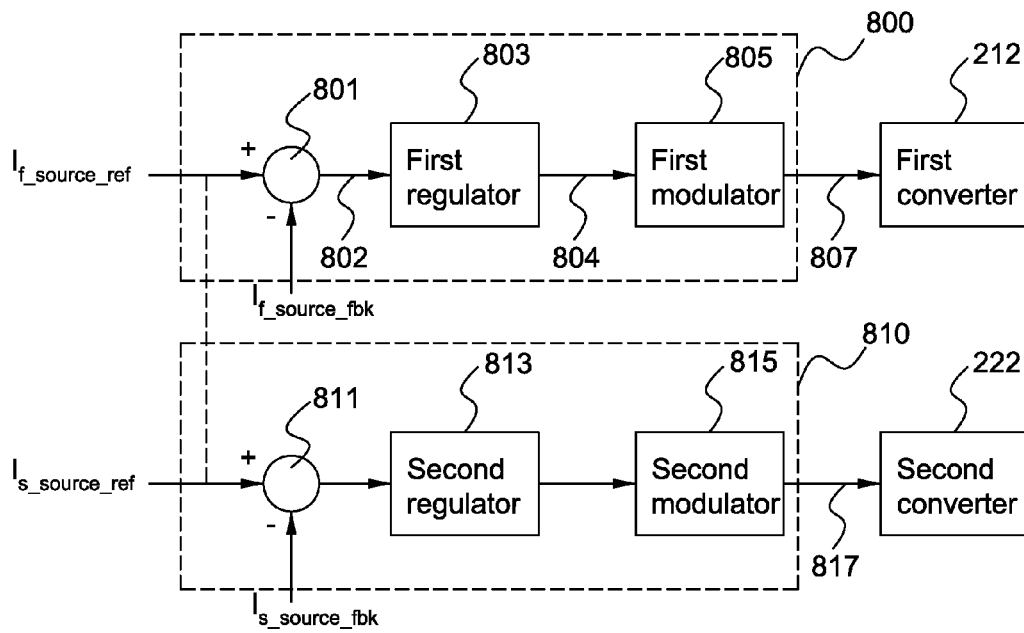


FIG. 8

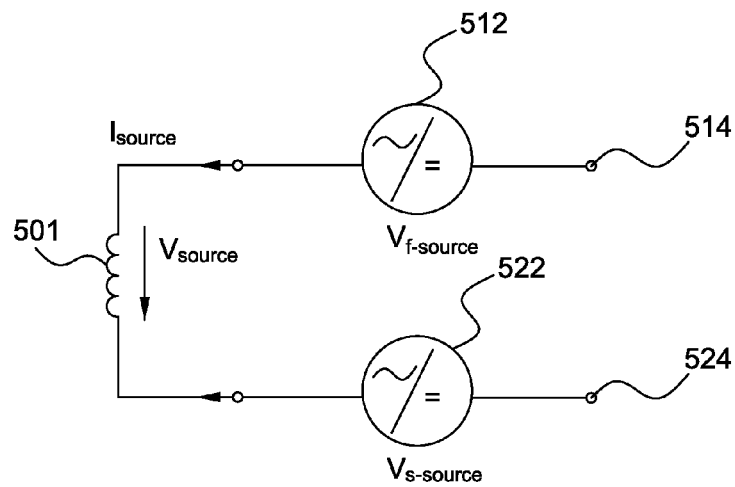


FIG. 9

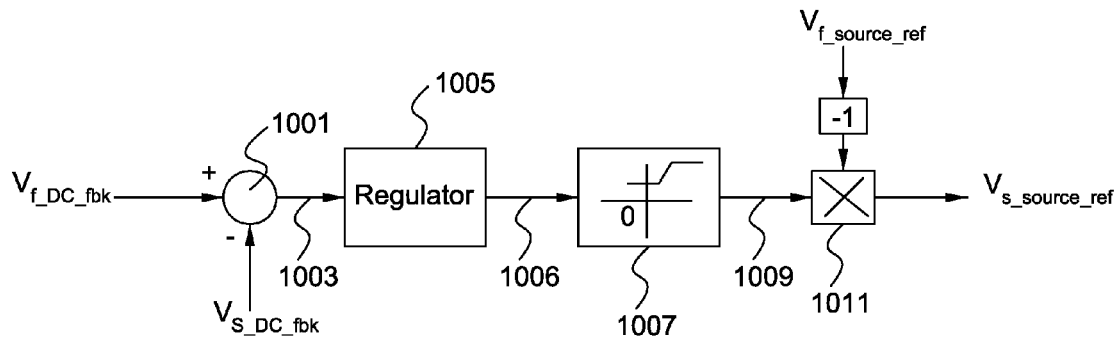


FIG. 10

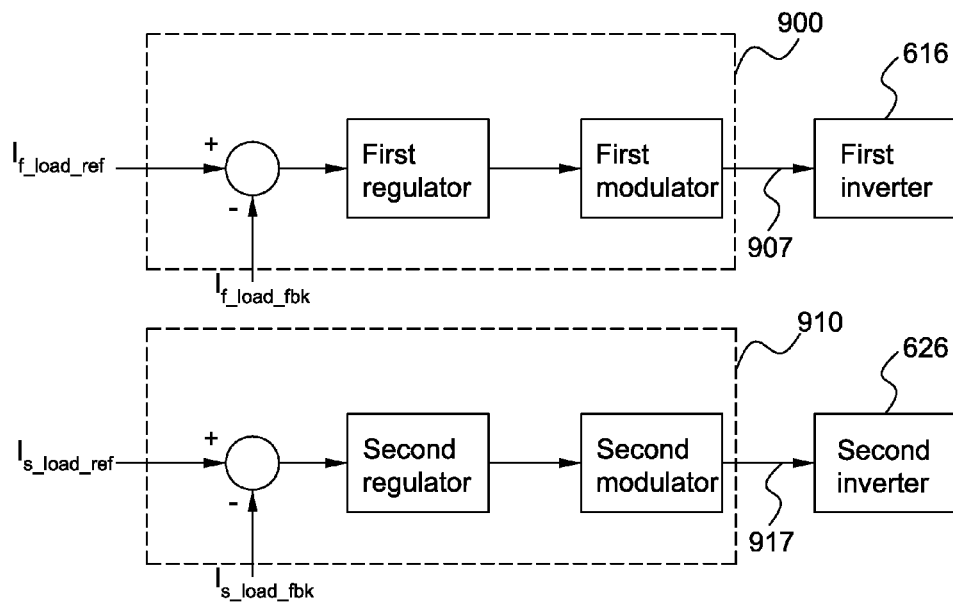


FIG. 11

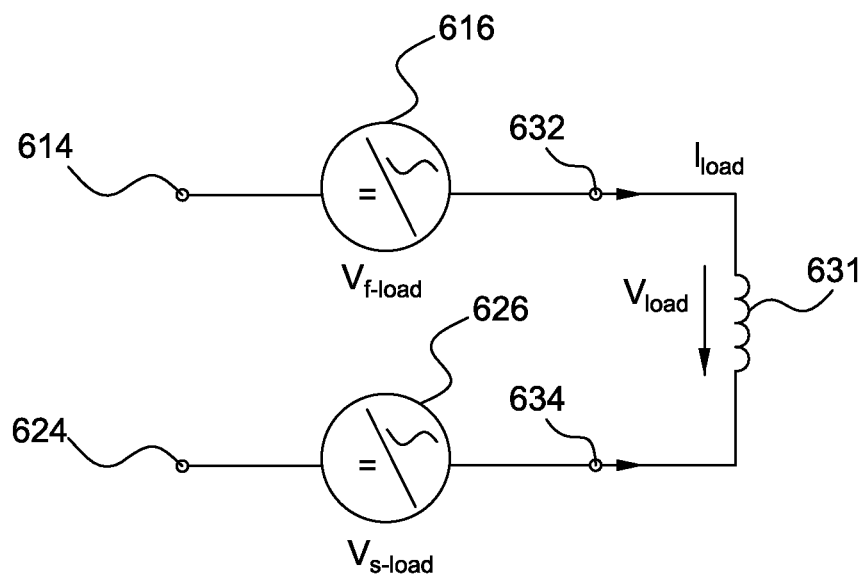


FIG. 12

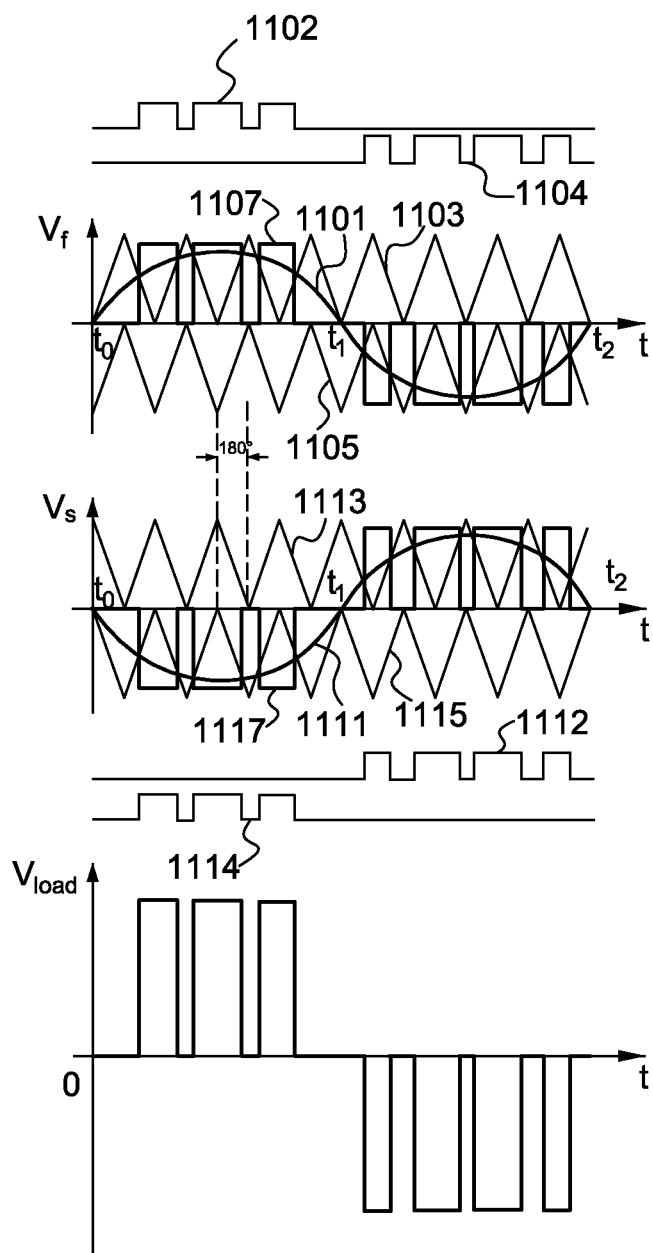


FIG. 13

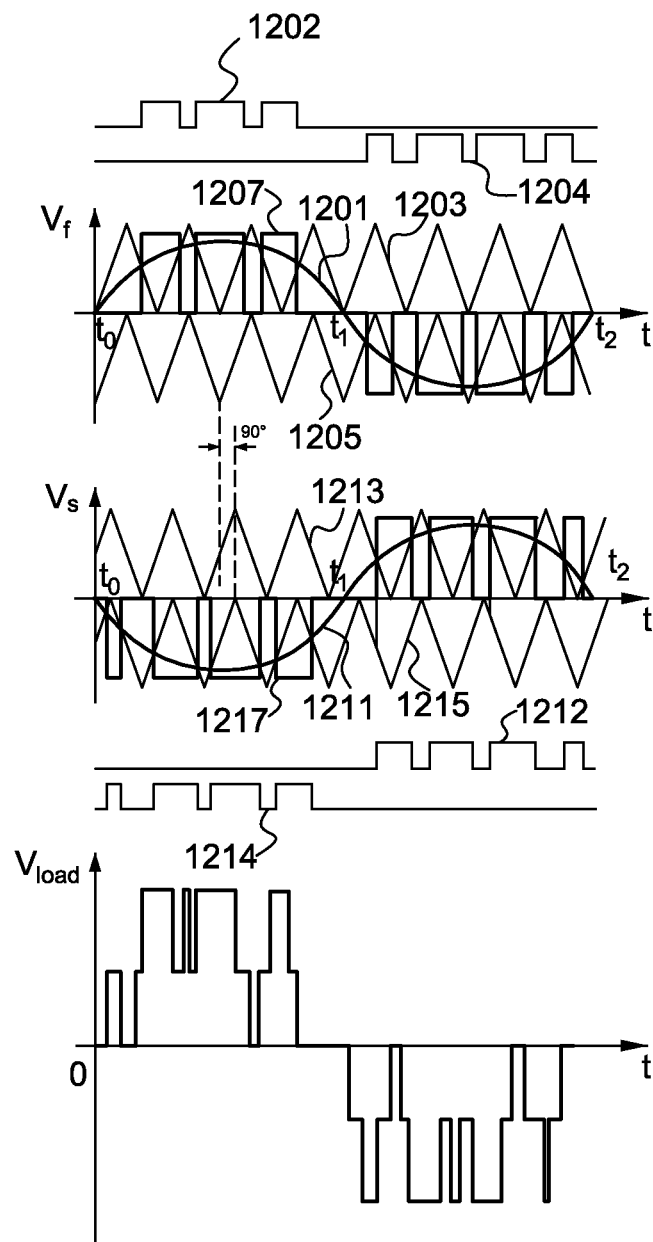


FIG. 14

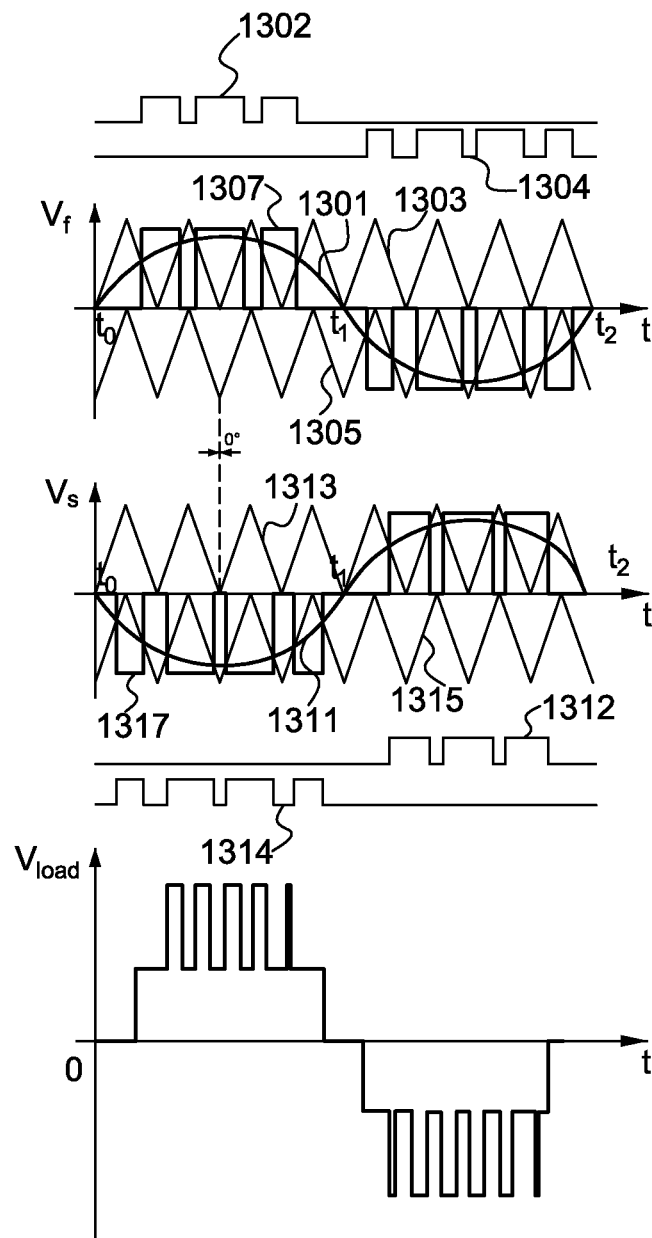


FIG. 15

## POWER CONVERSION SYSTEM AND METHOD

### BACKGROUND

This disclosure generally relates to power conversion systems and methods for balancing at least a first DC link voltage and a second DC link voltage.

For most power conversion systems, switching type semiconductors (e.g., IGBTs) are commonly used and controlled to conduct current so as to accomplish a power conversion process (e.g., DC to AC and/or AC to DC). However, due to the voltage and/or current limitation of the semiconductors, it is difficult to achieve a high-power rating power conversion system. Attempts to increase voltage rating and current conduction capability have been made to handle high power.

In some power conversion systems, various new topologies are used to increase current conduction capability. For example, one topology that has been proposed is employing two or more power conversion modules with the same structure coupled in parallel in the power conversion system to increase current conduction capability. However, by increasing the load current, the conduction loss of the power conversion system increases significantly. Furthermore, it is difficult to use suitable cables and circuit breakers when the load current is too high.

In some power conversion systems, loads designed with an open-winding structure are commonly used to increase voltage rating. With the open-winding structure, the load can be supplied with power by dual power conversion modules in a push-pull manner, and each power conversion module handles half of the total voltage. In some applications, in order to control the power conversion modules in the same manner independently, it is desired that the DC link voltages in different power conversion modules can be controlled to be balanced. However, conventional strategies for balancing the DC link voltages are complex.

Therefore, it is desirable to provide systems and methods to address at least one of the above-mentioned problems.

### BRIEF DESCRIPTION

One aspect of the present invention resides in a power conversion system. The power conversion system includes a first power conversion module, a second power conversion module, and a controller. The first power conversion module is coupled with a power source module via one or more first input terminals. The first power conversion module is configured to convert a first input power at the one or more first input terminals to a first output power at one or more first output terminals for providing to a load module. The first power conversion module includes a first source side converter, a first load side converter, and a first DC link coupled between the first source side converter and the first load side converter. The second power conversion module is coupled with the power source module via one or more second input terminals. The second power conversion module is configured to convert a second input power at the one or more second input terminals to a second output power at one or more second output terminals for providing to the load module. The second power conversion module includes a second source side converter, a second load side converter, and a second DC link coupled between the second source side converter and the second load side converter. The controller is in electrical communication with the first power conversion module and the second power conversion module. The controller is configured to generate a number of switching signals according to a circuit structure of

the power source module or a circuit structure of the load module. The switching signals are provided to the first power conversion module and the second power conversion module to balance a first DC link voltage at the first DC link and a second DC link voltage at the second DC link.

Another aspect of the present invention resides in a method for operating a power conversion system. The method includes generating a number of switching signals according to a circuit structure of a power source module or a circuit structure of a load module. The method includes providing the switching signals to a first power conversion module and a second power conversion module to balance a first DC link voltage at a first DC link and a second DC link voltage at a second DC link.

Yet another aspect of the present invention resides in a wind power conversion system. The wind power conversion system includes a wind generator, a first power conversion module, a second power conversion module, and a controller. The wind generator is for providing a first input power at one or more first input terminals and a second input power at one or more second input terminals. The first power conversion module is coupled with the wind generator via the one or more first input terminals. The first power conversion module is configured to convert the first input power to a first output power at one or more first output terminals for providing to a power grid. The first power conversion module includes a first rectifier, a first inverter, and a first DC link coupled between the first rectifier and the first inverter. The second power conversion module is coupled with the wind generator via the one or more second input terminals. The second power conversion module is configured to convert the second input power to a second output power at one or more second output terminals for providing to a load module. The second power conversion module includes a second rectifier, a second inverter, and a second DC link coupled between the second rectifier and the second inverter. The controller is in electrical communication with the first power conversion module and the second power conversion module. The controller is configured to generate a number of source side switching signals according to a winding-structure of the generator for providing to the first rectifier and the second rectifier, to reduce the voltage difference between a first DC link voltage at the first DC link and a second DC link voltage at the second DC link.

### DRAWINGS

These and other features, aspects, and advantages of the present disclosure will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

FIG. 1 is a block diagram of a power conversion system in accordance with an illustrative embodiment;

FIG. 2 is a schematic diagram of a power conversion system with a non-open-winding generator as a power source module in accordance with an illustrative embodiment;

FIG. 3 is a schematic diagram of a power conversion system with a non-open-winding generator as a power source module in accordance with another illustrative embodiment;

FIG. 4 is a schematic diagram of a power conversion system with dual separate power sources as a power source module in accordance with an illustrative embodiment;

FIG. 5 is a schematic diagram of a power conversion system with an open-winding generator as a power source module in accordance with an illustrative embodiment;



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FIG. 6 is a schematic diagram of a power conversion system with a motor as a load module in accordance with an illustrative embodiment;

FIG. 7 is a schematic diagram of a power conversion system with a DC load as a load module in accordance with an illustrative embodiment;

FIG. 8 is a control block diagram implemented by the first and second source side converters shown in FIGS. 2 and/or 3 for controlling current in accordance with an illustrative embodiment;

FIG. 9 is an equivalent circuit diagram of a part of a power conversion system with an open-winding power source module in accordance with an illustrative embodiment;

FIG. 10 is a schematic diagram for calculating a source side dynamic coefficient in accordance with an illustrative embodiment;

FIG. 11 is a control block diagram implemented by the first and second load side converters shown in FIG. 6 for controlling current in accordance with an illustrative embodiment;

FIG. 12 is an equivalent circuit diagram of a part of a power conversion system with an open-winding motor as the load module in accordance with an illustrative embodiment;

FIG. 13 is a waveform diagram illustrating various carrier and modulation waveforms of a carrier-based modulation method implemented by the power conversion system shown in FIG. 1 in accordance with an illustrative embodiment;

FIG. 14 is a waveform diagram illustrating various carrier and modulation waveforms of another carrier-based modulation method used in the power conversion system shown in FIG. 1 in accordance with an illustrative embodiment; and

FIG. 15 is a waveform diagram illustrating various carrier and modulation waveforms of another carrier-based modulation method used in the power conversion system shown in FIG. 1 in accordance with an illustrative embodiment.

#### DETAILED DESCRIPTION

In an effort to provide a concise description of these embodiments, not all features of an actual implementation are described in one or more specific embodiments. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

Unless defined otherwise, technical and scientific terms used herein have the same meaning as is commonly understood by one of ordinary skill in the art to which this disclosure belongs. The terms "first," "second," and the like, as used herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another. Also, the terms "a" and "an" do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced items. The term "or" is meant to be inclusive and mean either any, several, or all of the listed items. The use of "including," "comprising," or "having," and variations thereof herein are meant to encompass the items listed thereafter and equivalents thereof as well as additional items. The terms "connected" and "coupled" are not restricted to physical or mechanical connections or couplings, and can include electrical connections or couplings, whether direct or indirect. Furthermore, the terms "circuit" and "circuitry" and "control-

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ler" may include either a single component or a plurality of components, which are either active and/or passive and may be optionally be connected or otherwise coupled together to provide the described function.

As used herein, the terms "may," "can," "may be," and "can be" indicate a possibility of an occurrence within a set of circumstances; a possession of a specified property, characteristic or function; and/or qualify another verb by expressing one or more of an ability, capability, or possibility associated with the qualified verb. Accordingly, usage of "may," "can," "may be," and "can be" indicate that a modified term is apparently appropriate, capable, or suitable for an indicated capacity, function, or usage, while taking into account that in some circumstances, the modified term may sometimes not be appropriate, capable, or suitable. For example, in some circumstances, an event or capacity may be expected, while in other circumstances, the event or capacity may not occur. This distinction is captured by the terms "may," "can," "may be," and "can be".

Referring to FIG. 1, a block diagram of a power conversion system 100 in accordance with an illustrative embodiment is shown. As indicated in FIG. 1, for example, the power conversion system 100 includes a power source module 101, a first power conversion module 111, a second power conversion module 121, a controller 123, and a load module 131. The power conversion system 100 is used to convert an input electrical power generated from the power source module 101 to an output electrical power for providing to the load module 131. In other embodiments, the power conversion system 100 may be used to convert electrical power generated from the load module 131 to a suitable form for supplying to the power source module 101.

As indicated in FIG. 1, for example, a single power source is used as the power source module 101 for providing a first input power at one or more first input terminals 102 and a second input electrical power at one or more second input terminals 104. Both the first input power and the second input power can include DC power and/or AC power based on the form of the single power source. The first power conversion module 111 and the second power conversion module 121 are coupled with the power source module 101 via the one or more first input terminals 102 and the one or more second input terminals 104, respectively.

As indicated in FIG. 1, for example, the first power conversion module 111 and the second power conversion module 121 can be configured with the same topology. In the illustrated embodiment, the first power conversion module 111 includes a first source side converter 112, a first load side converter 116, and a first DC link 114 coupled between the first source side converter 112 and the first load side converter 116. The first source side converter 112 is coupled with the power source module 101 via the one or more first input terminals 102, and the first load side converter 116 is coupled with the load module 131 via one or more first output terminals 132.

Similarly, the second power conversion module 121 includes a second source side converter 122, a second load side converter 126, and a second DC link 124 coupled between the second source side converter 122 and the second load side converter 126. The second source side converter 122 is coupled with the power source module 101 via the one or more second input terminals 104, and the second load side converter 126 is coupled with the load module 131 via one or more second output terminals 134.

In one embodiment, each of the first and second source side converters 112, 122, the first and second load side converters 116, 126 may include a single converter. In other embodi-

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ments, each of the first and second source side converters **112**, **122**, the first and second load side converters **116**, **126** may include two or more converters coupled in parallel. This type of configuration can enhance the fault tolerance capability of the power conversion system **100**. Once one converter in the first or second source side converters **112**, **122**, the first or second load side converters **116**, **126** has a fault or fails, the power conversion system **100** can operate using the other functional converters.

The first power conversion module **111** is configured to convert the first input power to a first output power at the one or more first output terminals **132** for providing to the load module **131**. The second power conversion module **121** is configured to convert the second input power to a second output power at the one or more second output terminals **134** for providing to the load module **131**. The load module **131** operates on both of the first output power and the second output power.

For particular applications, the power source module **101** may include one or more DC power sources which supply DC electrical power to the first and second power conversion module **111**, **121**. In a more specific embodiment, the power source module **101** may include solar power sources, such as solar panels, and/or battery modules, such as fuel cells that can be operated to supply DC electrical power.

Regarding the DC power source module **101**, the first input power is a first DC input electrical power and the second input power is a second DC input electrical power. Both of the first source side converter **112** and the second source side converter **122** include DC/DC power converters for converting the first DC input electrical power and the second DC input electrical power to a first DC link power at the first DC link **114** and a second DC link power at the second DC link **124**. For particular configurations, the DC/DC power converter may include a boost circuit, a buck circuit, or any other suitable circuits which can convert a DC power into another DC power.

For particular applications, the power source module **101** supplies AC electrical power. In a more specific application, the power source module **101** includes a wind turbine, an AC generator or a power grid that can be operated to supply AC electrical power.

Regarding the AC power source module **101**, the first input power is a first AC input electrical power, and the second input power is a second AC input electrical power. Both the first source side converter **112** and the second source side converter **122** include AC/DC power converters for converting the first AC input electrical power and the second AC input electrical power to a first DC link power at the first DC link **114** and a second DC link power at the second DC link **124**. For particular applications, the AC/DC power converter may include an H-bridge converter, a three-phase rectifier or any other suitable circuitry which can convert an AC power into a DC power.

For particular applications, when the load module **131** operates on DC electrical power, both the first load side converter **116** and the second load side converter **126** include DC/DC power converters for converting the first DC link power and the second DC link power into a first output DC electrical power and a second output DC electrical power respectively.

For particular applications, when the load module **131** operates on AC electrical power, both the first load side converter **116** and the second load side converter **126** include DC/AC power converters for converting the first DC link

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power and the second DC link power into a first output AC electrical power and a second output AC electrical power respectively.

Beneficially, the dual power conversion module topology as illustrated in FIG. **1** can achieve a higher power level. Also, redundant arrangement of the power converters can help enhance the reliability of the power conversion system **100**. However, DC voltages applied to each of the first and second power conversion modules **111**, **121** may become unbalanced if the DC link voltages are not controlled effectively. Also, a load current waveform may be distorted and need to be optimized according to the requirements of the load module. Therefore, several control strategies/algorithms are proposed and implemented in the controller **123** to maintain a first DC link voltage at the first DC link **114** and a second DC link voltage at the second DC link **124** at the same value in a simple and effective way.

The controller **123** is in electrical communication with the first power conversion module **111** and the second power conversion module **121**. The controller **123** may include any suitable programmable circuits or devices such as a digital signal processor (DSP), a field programmable gate array (FPGA), a programmable logic controller (PLC), and an application specific integrated circuit (ASIC). In some embodiments, the controller **123** may be implemented in the form of hardware, software, or a combination of hardware and software. The controller **123** is configured to generate a number of switching signals mainly according to different circuit structures of the power source module **101** or different circuit structures of the load module **131**. Although a single controller **123** is illustrated to facilitate explanation, in some embodiments, two separate controllers can be arranged.

For particular configurations, when the power source module **101** includes different circuit structures, the switching signals include a number of first and second source side switching signals generated by different strategies/algorithms. The first and second source side switching signals are provided to the first source side converter **112** and second source side converter **122** respectively, for controlling the first power conversion module **111** and the second power conversion module **121** to receive the same amount of power from the power source module **101**.

For these configurations, the switching signals include a number of first and second load side switching signals generated based on a voltage control strategy. The first and second load side switching signals are provided to the first load side converter **116** and the second load side converter **126** respectively to ensure all the first DC link power at the first DC link **114** and all the second DC link power at the second DC link **124** can be provided to the load module **131**. By operating the first and second source side converters **112**, **122** with the first and second source side switching signals, the two DC link voltages can be balanced.

For particular configurations, when the load module **131** includes different circuit structures, the switching signals include a number of first and second load side switching signals generated by different strategies. The first and second load side switching signals are provided to the first load side converter **116** and the second load side converter **126** respectively, for controlling the first power conversion module **111** and the second power conversion module **121** to provide the same amount of power to the load module **131**.

For these configurations, the switching signals include a number of first and second source side switching signals generated based on a voltage control strategy, for providing to the first source side converter **112** and the second source side converter **122** respectively to ensure the power source module

**101** can provide as much first input power and second input power as the load module **131** needs. By operating the first and second load side converters **116**, **126** with the first and second load side switching signals, the two DC link voltages can be balanced.

When the power source module **101** includes a wind generator, and the load module **131** includes a transformer for providing an output power obtained from the first output power and the second output power to a power grid, the power conversion system **100** can be referred to as a wind power conversion system. For particular configurations of the wind power conversion system **100**, a first rectifier and a second rectifier are used as the first and second source side converters **112**, **122**, respectively. The first and second rectifiers are used to convert a first input AC electrical power and a second input AC electrical power to the first DC link power and the second DC link power, respectively. A first inverter and a second inverter are used as the first and second load side converters **116**, **126**, respectively. The first and second inverters **111**, **121** are used to convert the first DC link power and the second DC link power to first AC output power and second AC output power, respectively. A number of first and second source side switching signals are generated by the controller **123** according to the circuit structure or winding-structure of the wind generator to balance the first DC link voltage and the second DC link voltage.

Referring to FIG. 2, a schematic diagram of a power conversion system **200** with a non-open-winding generator as the power source module **101** shown in FIG. 1 in accordance with an illustrative embodiment is shown. The power conversion system **200** is similar to the power conversion system **100** shown in FIG. 1. The power conversion system **200** also includes a power source module **201**, a first power conversion module **211**, a second power conversion module **221**, a controller **223**, and a load module **231**.

However, the first input power and the second input power are commonly supplied from a generator **201** with a non-open-winding structure. For the example arrangement shown in FIG. 2, a three-phase generator with a single set of Y-connection windings is used as the power source module **201**. The generator **201** includes three windings W1, W2, and W3, and each winding includes two terminals. One terminal of each winding is tied together to form a neutral point O. The other terminals of the three windings W1, W2, and W3 are coupled with both the first power conversion module **211** and the second power conversion module **221** via corresponding input terminals A, B, and C respectively. In other embodiments, the wind generator of the power source module **201** may include any number of windings. These windings can also be connected to form other shapes, such as delta-shaped and triangular-shaped connections.

As indicated in FIG. 2, for example, a first converter **212** is used as the first source side converter and a first inverter **216** is used as the first load side converter in the first power conversion module **211**. A second converter **222** is used as the second source side converter, and a second inverter **226** is used as the second load side converter in the second power conversion module **221**.

For the arrangement shown in FIG. 2, the load module **131** includes an open-winding structure. Different from the non-open-winding structure (e.g., the generator **201** shown in FIG. 2), the windings are not tied together. An open-winding structure is configured with a number of separate windings, and each winding has two terminals. The two terminals of each winding are coupled to the first power conversion module **211** and the second power conversion module **221** respectively. Therefore, the open-winding load **231** is coupled with the first

power conversion module **211** and the second power conversion module **221** in series to allow same amount of electrical current to flow between corresponding phase output terminal of the first inverter **116** and the second inverter **226**. In some embodiments, the load module **131** includes non-open-winding structure.

As indicated in FIG. 2, for example, a three-phase open-winding transformer is used as the load module **231**. The transformer **231** includes an open-winding primary side and a secondary side. In the open-winding primary side, each of three windings T1, T2, and T3 is coupled with the first inverter **216** and the second inverter **226** via first output terminals **232** and second output terminals **234**. In some embodiments, the secondary side of the transformer **231** includes an open-winding structure. In some embodiments, the secondary side can provide electrical power to a power grid.

Referring to FIG. 3, a schematic diagram of another power conversion system **300** with a non-open-winding generator as the power source module **101** shown in FIG. 1 in accordance with an illustrative embodiment is shown. Compared with the power conversion system **200** shown in FIG. 2, similarly, the power conversion system **300** also includes a power source module **301**, a first power conversion module **311**, a second power conversion module **321**, a controller **323**, and a load module **331**.

However, a three-phase generator **301** with a double set of Y-connection windings is used as the power source module **301** to provide the first input power and the second input power. One set of the Y-connection windings is coupled to the first converter **312** and the neutral point O1 via three windings Wa1, Wb1, and Wc1. The other set of Y-connection windings is coupled to the second converter **322** and the neutral point O2 via three windings Wa2, Wb2, and Wc2.

Referring to FIG. 4, a schematic diagram of a power conversion system **400** with dual separate power sources as the power source module **101** shown in FIG. 1 in accordance with an illustrative embodiment is shown. Compared with the power conversion system **200** shown in FIG. 2, similarly, the power conversion system **400** also includes a power source module **401**, a first power conversion module **411**, a second power conversion module **421**, a controller **423**, and a load module **431**.

However, the power source module **401** includes a first power source **403** and a second power source **405** which is separately arranged from the first power source **403**. The first power source **403** is used to provide the first input power, and the second power source **405** is used to provide the second input power.

For the arrangement shown in FIG. 4, a first DC power source (e.g., a first solar panel battery, and/or fuel cell) is used as the first power source **403**, and a second DC power source (e.g., a second solar panel, battery, and/or fuel cell) is used as the second DC power source **405**.

Referring to FIG. 5, a schematic diagram of a power conversion system **500** with an open-winding generator as the power source module **101** shown in FIG. 1 in accordance with an illustrative embodiment is shown. Compared with the power conversion system **200** shown in FIG. 2, similarly, the power conversion system **500** also includes a power source module **501**, a first power conversion module **511**, a second power conversion module **521**, a controller **523**, and a load module **531**.

However, the power source module **501** includes an open-winding generator for providing the first input power and the second input power. In the illustrated embodiment, the generator **501** is a three-phase open-winding generator. Each of three windings W1, W2, and W3 is coupled to each input

three-phase of first converter **512** and second converter **522** via one of the corresponding first input terminals **502** and one of the corresponding second input terminals **504**.

Referring to FIG. 6, a schematic diagram of a power conversion system **600** with a motor as the load module in accordance with an illustrative embodiment is shown. The power conversion system **600** is similar to the power conversion system **100** shown in FIG. 1. The power conversion system **600** also includes a power source module **601**, a first power conversion module **611**, a second power conversion module **621**, a controller **623**, and a load module **631**.

However, the power source module **601** includes a transformer for receiving electrical power from the power grid and providing the first input power and the second input power at first input terminals **602** and second input terminals **604** respectively. In some embodiments, the transformer **601** includes an open-winding structure as indicated in FIG. 2. For particular configurations, the transformer **601** includes a non-open-winding structure.

As indicated in FIG. 6, for example, a three-phase open-winding transformer is used as the power source module **601**. The transformer **601** includes a primary side and an open-winding secondary side. In the open-winding secondary side, each of three windings T1, T2, and T3 is coupled with the first converter **612** and the second converter **622** via first input terminals **602** and second input terminals **604**. For particular configurations, the primary side of the transformer **601** includes an open-winding structure. For particular configurations, the primary side can receive electrical power from a power grid.

For the arrangement shown in FIG. 6, the load module **631** includes a motor coupled between the first power conversion module **611** and the second conversion module **621** via the first output terminals **632** and second output terminals **634** respectively.

For particular configurations, a motor with a non-open-winding structure such as the structure of Y-connection windings of the generator **201** shown in FIG. 2 or the double sets of Y-connection windings of the generator **301** shown in FIG. 3 is used as the motor **631**. For particular configurations, a motor with delta-shaped or triangular-shaped-connection windings (not shown) may be used as the motor **631**.

For particular configurations, a motor with an open-winding structure such as the structure of an open-winding generator **501** shown in FIG. 5 may be used as the motor **631**.

Referring to FIG. 7, a schematic diagram of a power conversion system **700** with a DC load in accordance with an illustrative embodiment is shown. Compared with the power conversion system **600** shown in FIG. 6, similarly, the power conversion system **700** also includes a power source module **701**, a first power conversion module **711**, a second power conversion module **721**, a controller **723**, and a load module **731**.

However, the load module **731** includes a DC load coupled between the first power conversion module **711** and the second conversion module **721** via first output terminals **732** and second output terminals **734** respectively.

FIGS. 2-5 illustrate a number of exemplary circuit structures for the power source module **101** that may be used in the power conversion system **100**. The influence of the circuit structure of the power source module **101** on the switching signals will be described in detail below.

The first and second load side switching signals provided to the first inverter (e.g., **216**) and the second inverter (e.g., **226**) as shown in FIGS. 2-5 are generated based at least in part on a voltage control strategy. Taking the power conversion system **200** shown in FIG. 2 for example, the corresponding

output voltage space vectors of the first and second inverters **216**, **226** can be controlled to have the same value with a reverse phase. Therefore, each first and corresponding second load side voltage references of each phase on the first and second inverters **216**, **226** for modulation are:

$$\vec{V}_{f\_load\_ref} = \vec{V}_{s\_load\_ref} \quad (1),$$

where  $\vec{V}_{f\_load\_ref}$  and  $\vec{V}_{s\_load\_ref}$  represent a first load side voltage reference and a second load side voltage reference of one phase.

The first and second source side switching signals provided to the first converter (e.g., **212**) and the second converter (e.g., **222**) as shown in FIGS. 2-5 are generated based at least in part on the circuit structure of the power source module (e.g., **201**) to control the first converter (e.g., **212**) and the second converter (e.g., **222**).

Taking the power conversion system **200** or the power conversion system **300** shown in FIG. 2 or FIG. 3 for example. The power source module (e.g., **201** or **301**) includes a non-open-winding generator. A current control strategy for generating the first source side switching signals and the second source side switching signals is proposed to receive the same amount of the first input active power and the second input active power.

For example, the non-open-winding generator **201** shown in FIG. 2 is designed to provide the same source side voltage  $\vec{V}_{source}$  to the first converter **212** and the second converter **222** at the points A, B, and C. In order to receive the same amount of the first input active power and the second input active power, the input current vector of the first and second converters **212**, **222** should be controlled to have the same value with the same phase. Therefore, each first and second source side current references of each phase on the first and second converters **212**, **222** for modulation are:

$$\vec{I}_{f\_source\_ref} = \vec{I}_{s\_source\_ref} \quad (2),$$

where  $\vec{I}_{f\_source\_ref}$  and  $\vec{I}_{s\_source\_ref}$  represent a first source side current reference and a second source side current reference of one phase. When the first source side current and the second source side current are controlled to be equal, the first input active power  $P_{f\_source}$  and the second active input power  $P_{s\_source}$  can be controlled to be equal.

The first output active power  $P_{f\_load}$  is proportional to the first DC link voltage and the second output active power  $P_{s\_load}$  is proportional to the second DC link voltage, which can be expressed by the following equation:

$$\begin{cases} P_{f\_load} = 1.5 \vec{V}_{f\_load} \cdot \vec{I}_{load} = 1.5 \left( \frac{V_{f\_DC\_fbk}}{V_{dc\_rated}} \right) \vec{V}_{f\_load\_ref} \cdot \vec{I}_{load} \\ P_{s\_load} = 1.5 \vec{V}_{s\_load} \cdot (-\vec{I}_{load}) = 1.5 \left( \frac{V_{s\_DC\_fbk}}{V_{dc\_rated}} \right) \vec{V}_{s\_load\_ref} \cdot (-\vec{I}_{load}) \end{cases} \quad (3)$$

where  $\vec{I}_{load}$  represents load side current flowing through the first or the second load side converters **216**, **226** via the transformer **231**.  $\vec{V}_{f\_load}$  and  $\vec{V}_{s\_load}$  represent the first load side voltage vector and the second load side voltage vector respectively,  $V_{f\_DC\_fbk}$  and  $V_{s\_DC\_fbk}$  represent the first feedback DC link voltage and the second feedback DC link voltage respectively, and  $V_{dc\_rated}$  represents a rated DC voltage of the first or second DC link.

From equation (1) and (3), it can be found that when the first feedback DC link voltage  $V_{f\_DC\_fbk}$  is higher than that of the second feedback DC link voltage  $V_{s\_DC\_fbk}$  the first the

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first inverter **216** will supply more power to the load module **231** and the first DC link voltage will decrease. When the first feedback DC link voltage  $V_{f\_DC\_fbk}$  is lower than that of the second feedback DC link voltage  $V_{s\_DC\_fbk}$ , the second inverter **226** will supply more power to the load module **231** and the second DC link voltage will decrease. With the current control strategy, the first DC link voltage and the second DC link voltage can be balanced automatically.

Referring to FIG. 8, a control block diagram implemented by the power conversion system **200** shown in FIG. 2 or the power conversion system **300** shown in FIG. 3 for controlling current in accordance with an illustrative embodiment is shown. Taking the power conversion system **200** for example, the source side switching signals generated by the controller **223** are provided to the first and second converters **212**, **222** based at least in part on one or more first source side current references **241** and one or more second source side current references **242**.

As indicated in FIG. 8, for example, for each phase of the generator **201**, a first current control loop **800** and a second current control loop **810** are implemented by the controller **223** to generate the first source side switching signals **807** and the second source side switching signals **817** respectively. The first source side switching signals **807** are used to operate the first converter **212** for controlling a first source side feedback current signal  $I_{f\_source\_fbk}$  to track a first source side current reference  $I_{f\_source\_ref}$ . Similarly, the second source side switching signals **817** are used to operate the second converter **222** for controlling a second source side feedback current signal  $I_{s\_source\_fbk}$  to track a second source side current reference  $I_{s\_source\_ref}$ . In some embodiments,  $I_{f\_source\_ref}$  and  $I_{s\_source\_ref}$  have the same value. In some embodiments,  $I_{f\_source\_fbk}$  and  $I_{s\_source\_fbk}$  can be measured by sensors. For particular configurations, the sensors include resistors, hall-effect sensors, and fiber optic sensors.

As indicated in FIG. 8, the first current control loop **800** and the second current control loop **810** can be implemented in the same manner, for example, both of them include a summation element, a regulator, and a modulator. In some embodiments, other elements (e.g., magnitude limiting elements) can be added to the first current control loop **800** and/or the second current control loop **810**. In a more specific application, in the first current control loop **800**, a difference **802** is calculated by a subtraction of  $I_{f\_source\_ref}$  and  $I_{f\_source\_fbk}$  via a summation element **801**. The difference **802** is sent to a first regulator **803** which outputs a signal **804**. The signal **804** is sent to a first modulator **805** which is configured for generating the first source side switching signals **807** by implementing one or more modulation algorithms, such as a pulse width modulation (PWM) or a current hysteresis comparison algorithm.

For particular configurations, the second source side switching signals **817** from the second current control loop **810** are obtained in a similar manner as the first source side switching signals **807** from the first current control loop **800** shown in FIG. 8. For particular configurations, the second source side switching signals **817** are obtained in a different manner, that is, the first regulator **803** and a second regulator **813** are configured to implement different control algorithms such as a fuzzy algorithm and a neural network algorithm, respectively.

Then, the first source side switching signals **807** and the second source side switching signals **817** can be sent to the first converter **212** and the second converter **222** respectively to enable the two converters **212**, **222** to receive the same amount of first input active power and second input active power. As a result, the first DC link voltage and the second DC link voltage can be balanced or maintained at the same value.

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Taking the power conversion system **400** shown in FIG. 4 for example, the power conversion system **400** includes dual separate power sources in the power source module **401**. A power control strategy for generating the first source side switching signals and the second source side switching signals is proposed to receive the same amount of the first input power and the second input power.

The source side switching signals generated by the controller **423** are provided to the first and second converters **412**, **422** based at least in part on a first source side power reference  $P_{f\_source\_ref}$  **441** and a second source side power reference  $P_{s\_source\_ref}$  **442**. Similar to the closed-loop control strategy shown in FIG. 8, the first source side switching signals **807** can be used to operate the first converter **412** for controlling a first source side feedback power signal  $P_{f\_source\_fbk}$  to track a first source side power reference  $P_{f\_source\_ref}$  and the second source side switching signals **817** can be used to operate the second converter **422** for controlling a second source side feedback power signal  $P_{s\_source\_fbk}$  to track a second source side power reference  $P_{s\_source\_ref}$ .

For particular configurations, receiving the same amount of power can be achieved by controlling the first feedback current and/or voltage signals at the first converter **412** and second feedback current and/or voltage signals at the second converter **422** based at least in part on the current and/or voltage references.

Taking the power conversion system **500** shown in FIG. 5 for example, the power conversion system **500** includes an open-winding generator **501** in the power source module. A voltage control strategy for generating the first source side switching signals and the second source side switching signals is proposed to receive the same amount of the first input active power and the second input active power.

Referring to FIG. 9, an equivalent circuit diagram of a part of a power conversion system **500** with an open-winding generator **501** in accordance with an illustrative embodiment is shown. As indicated in FIG. 9, the first converter **512** and the second converter **522** are coupled in series with the open-winding generator **501** which means the inputs of the first converter **512** and the second converter **522** share a common current loop. Thus, the relationship of the current in the first converter **512**  $\vec{I}_{f\_source}$  and the current in the second converter **522**  $\vec{I}_{s\_source}$  is:

$$\vec{I}_{f\_source} = \vec{I}_{s\_source} \quad (4),$$

The source side switching signals generated by the controller **523** are provided to the first and second converters **512**, **522** based at least in part on one or more first source side voltage references **541** and one or more second source side voltage references **542**. Similar to the closed-loop control strategy shown in FIG. 8, the first source side switching signals **807** can be used to operate the first converter **512** for controlling a first source side feedback voltage signal  $V_{f\_source\_fbk}$  to track a first source side voltage reference  $V_{f\_source\_ref}$  **541** and the second source side switching signals **817** can be used to operate the second converter **522** for controlling a second source side feedback voltage signal  $V_{s\_source\_fbk}$  to track a second source side voltage reference  $V_{s\_source\_ref}$  **542**. A source side dynamic coefficient is set between each first source side voltage reference and each corresponding second source side voltage reference of each phase.

In some embodiments,  $V_{f\_source\_ref}$  is not equal to  $V_{s\_source\_ref}$  all the time due to the source side dynamic coefficient. In some embodiments,  $V_{f\_source\_fbk}$  and  $V_{s\_source\_fbk}$

can be measured by sensors. For particular configurations, the sensors include resistors, hall-effect sensors, and fiber optic sensors.

The amplitude of the source side dynamic coefficient will be regulated to one gradually and then the first DC link voltage and the second DC link voltage can be balanced. The source side dynamic coefficient changes based at least in part on the first feedback DC link voltage  $V_{f\_source\_fbk}$  and the second feedback DC link voltage  $V_{s\_source\_fbk}$ . Setting the source side dynamic coefficient so as to get  $V_{f\_source\_ref}$  and  $V_{s\_source\_ref}$  will be illustrated in detail below.

For a specific application, the source side dynamic coefficient is calculated based at least in part on a ratio between the first feedback DC link voltage and the second feedback DC link voltage measured by one or more sensors.

In order to balance the two DC link voltages by the first and second converters, in one embodiment, the first source side voltage reference is fixed, and the second source side voltage reference is tuned using the following equation:

$$V_{s\_source\_ref} = -\frac{V_{f\_DC\_fbk}}{V_{s\_DC\_fbk}} V_{f\_source\_ref}, \quad (5)$$

where  $V_{f\_DC\_fbk}$  and  $V_{s\_DC\_fbk}$  represent the first feedback DC link voltage and the second feedback DC link voltage, respectively. In another embodiment, the second source side voltage reference is fixed, and the first source voltage reference is tuned using the following equation:

$$V_{f\_source\_ref} = -\frac{V_{s\_DC\_fbk}}{V_{f\_DC\_fbk}} V_{s\_source\_ref} \quad (6)$$

From equations (5) and (6), it can be found that the source side voltage references of the first and second converters should have opposite directions and have the source side dynamic coefficient.

For another specific application, the source side dynamic coefficient is calculated based at least in part on a difference between a first feedback DC voltage and a second feedback DC voltage. In this application, the source side dynamic coefficient is obtained by a regulator which will be described in detail below with respect to FIG. 10.

Referring to FIG. 10, a schematic diagram for calculating a source side dynamic coefficient **1009** in accordance with an illustrative embodiment is shown. As indicated in FIG. 10, the second feedback DC link voltage  $V_{s\_DC\_fbk}$  is subtracted from the first feedback DC link voltage  $V_{f\_DC\_fbk}$  via a summation element **1001** and a difference **1003** is sent to a regulator **1005**. The regulator **1005** may be implemented by a proportion (P) control algorithm, a proportion and integration (PI) control algorithm or any other suitable control algorithms. In some embodiments, a limitation element **1007** is included. The limitation element **1007** receives a signal **1006** and outputs the source side dynamic coefficient **1009**. When the signal **1006** is a negative value, the source side dynamic coefficient **1009** is a lower limited value, when the signal **1006** is a positive value, the source side dynamic coefficient **1009** is a corresponding positive value and the corresponding positive value has an upper limited value.

As indicated in FIG. 10, for example, the source side dynamic coefficient **1009** is multiplied by a negated signal of the first source side voltage reference  $V_{f\_source\_ref}$  using a multiplication element **1011** to obtain the second source side

voltage reference  $V_{s\_source\_ref}$ . In other embodiments, the source side dynamic coefficient **1009** is multiplied by a negated signal of the second source side input voltage reference  $V_{s\_source\_ref}$  using the multiplication element **1011** to obtain the second source side input voltage  $V_{f\_source\_ref}$ .

FIGS. 6-7 illustrate a number of circuit structures for the load module **131** that may be used in the power conversion system **100**. Control strategies may be implemented, that are similar to the three control strategies illustrated above for generating different first and second source side switching signals based on the circuit structure of the power source module **101**. Three control strategies for generating different first and second load side switching signals based on the circuit structure of the load module **131** will be illustrated in detail below.

The voltage control strategy for generating the first and second load side switching signals shown in FIGS. 2-5 is used to generate the first and second source side switching signals in controlling the power conversion systems as shown in FIGS. 6-7. The input voltage space vector of the first and second converters **612**, **622** (or the first and second source side converters **712**, **722**) can be controlled to have the same value with a reverse phase. Therefore, each first and corresponding second source side voltage references of each phase on the first and second converters **612**, **622** for modulation are:

$$\vec{V}_{f\_source\_ref} = -\vec{V}_{s\_source\_ref} \quad (7),$$

where  $\vec{V}_{f\_load\_ref}$  and  $V_{s\_load\_ref}$  represent a first source side voltage reference and a second source side voltage reference of one phase.

Taking the power conversion system **600** shown in FIG. 6 for example, the motor may include a non-open-winding structure as the generator **201** shown in FIG. 2 or the generator **301** shown in FIG. 3. A current control strategy for generating the first load side switching signals and the second load side switching signals is proposed to provide the same amount of the first output active power and the second output active power to the non-open-winding motor **631**.

Referring to FIG. 11, a control block diagram implemented by the power conversion system **600** with a non-open winding motor shown in FIG. 6 for controlling current in accordance with an illustrative embodiment is shown. The load side switching signals generated by the controller **623** are provided to the first and second inverters **616**, **626** based at least in part on one or more first load side current references and one or more second load side current references.

As indicated in FIG. 11, for example, for each phase of the motor **631**, a first current control loop **900** and a second current control loop **910**, which are similar to the first current control loop **800** and the second current control loop **810** as shown in FIG. 8, are implemented by the controller **623** to generate the first load side switching signals **907** and the second load side switching signals **917** respectively. The first load side switching signals **907** are used to operate the first inverter **616** for controlling a first load side feedback current signal  $I_{f\_load\_fbk}$  to track a first load side current reference  $I_{f\_load\_ref}$  **641**. Similarly, the second load side switching signals **917** are used to operate the second inverter **626** for controlling a second load side feedback current signal  $I_{s\_load\_fbk}$  to track a second load side current reference  $I_{s\_load\_ref}$  **642**. For particular configurations,  $I_{f\_load\_ref}$  and  $I_{s\_load\_ref}$  have the same value. For particular configurations,  $I_{f\_load\_fbk}$  and  $I_{s\_load\_fbk}$  can be measured by sensors. For particular configurations, the sensors include resistors, hall-effect sensors, and fiber optic sensors.

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Taking the power conversion system **700** shown in FIG. 7 for example, the power conversion system **700** includes a DC load **731**. A power control strategy for generating the first load side switching signals and the second load side switching signals is proposed to provide the same amount of the first output power and the second output power to the DC load **731**.

The load side switching signals generated by the controller **723** are provided to the first and second load side converters **716**, **726** based at least in part on a first load side power reference  $P_{f\_load\_ref}$  **741** and a second load side power reference  $P_{s\_load\_ref}$  **742**. Similar to the closed-loop control strategy shown in FIG. 11, the first load side switching signals **907** can be used to operate the first load side converter **716** for controlling a first load side feedback power signal  $P_{f\_load\_fbk}$  to track a first load side power reference  $P_{f\_load\_ref}$  and the second load side switching signals **917** can be used to operate the second load side converter **726** for controlling a second load side feedback power signal  $P_{s\_load\_fbk}$  to track a second load side power reference  $P_{s\_load\_ref}$ .

For particular configurations, providing the same amount of power can be achieved by controlling the first feedback current and/or voltage signals at the first load side converter **716** and second feedback current and/or voltage signals at the second load side converter **726** based at least in part on the current and/or voltage references.

Taking the power conversion system **600** shown in FIG. 6 for example, the motor may include an open-winding structure as the generator **501** shown in FIG. 5. A voltage control strategy for generating the first load side switching signals and the second load side switching signals is proposed to provide the same amount of the first output active power and the second output active power to the open-winding motor **631**.

Referring to FIG. 12, an equivalent circuit diagram of a part of a power conversion system **600** with an open-winding motor in accordance with an illustrative embodiment is shown. As indicated in FIG. 12, the first inverter **616** and the second inverter **626** are coupled in series with the open-winding motor **631** which means the outputs of the first inverter **616** and the second inverter **626** share a common current loop. Thus, the relationship of the current in the first inverter **616**  $\vec{I}_{f\_load}$  and the current in the second inverter **626**  $\vec{I}_{s\_load}$  is:

$$\vec{I}_{f\_load} = \vec{I}_{s\_load} \quad (8),$$

The load side switching signals generated by the controller **623** are provided to the first and second inverters **616**, **626** based at least in part on one or more first load side voltage references and one or more second load side voltage references, respectively. Similar to the closed-loop control strategy shown in FIG. 11, the first load side switching signals **907** can be used to operate the first inverter **616** for controlling a first load side feedback voltage signal  $V_{f\_load\_fbk}$  to track a first load side voltage reference  $V_{f\_load\_ref}$ . The second load side switching signals **917** can be used to operate the second inverter **626** for controlling a second load side feedback voltage signal  $V_{s\_load\_fbk}$  to track a second load side voltage reference  $V_{s\_load\_ref}$ . A load side dynamic coefficient is set between a first load side voltage reference and a second load side voltage reference of each phase.

Similar to the source side dynamic coefficient set between the first source side voltage reference and the second source side voltage reference of each phase for controlling the power conversion system **500** shown in FIG. 5, the load side dynamic coefficient is calculated based at least in part on a

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ratio or a difference between the first feedback DC link voltage at the first DC link and the second feedback DC link voltage at the second DC link. Thus the details are omitted here.

When the load module **131** is a transformer used to provide electrical power to power grid, a carrier-based modulation method with different phase shifts is proposed to reduce the total harmonic distortion (THD) seen by the power grid. More specifically, the controller **123** is configured to implement the carrier-based modulation method with different phase shifts to generate load side switching signals for providing to the first load side converter **116** and the second load side converter **126**.

Referring to FIG. 13, a waveform diagram illustrating various carrier and modulation waveforms of a carrier-based modulation method used in the power conversion system shown in FIG. 1 in accordance with an illustrative embodiment is shown. Taking an open-winding transformer for example, as indicated in FIG. 13, a first modulation wave **1101**, a first positive carrier wave **1103**, and a first negative carrier wave **1105** are used to generate the first load side switching signals **1102**, **1104**. In a more specific application, the first modulation wave **1101** is a sinusoidal voltage wave, the first positive carrier wave **1103** is a triangular voltage wave, and the first negative carrier wave **1105** is a triangular voltage wave having the same phase with the first positive carrier wave **1103**.

From time  $t_0$  to  $t_1$ , when the first modulation wave **1101** is higher than the first positive carrier wave **1103**, an on switching signal is generated, when the first modulation wave **1101** is lower than the first positive carrier wave **1103**, an off switching signal is generated. From time  $t_1$  to  $t_2$ , when the first modulation wave **1101** is higher than the first negative carrier wave **1105**, an off switching signal is generated, when the first modulation wave **1101** is lower than the first negative carrier wave **1105**, an on switching signal is generated. Then, the first load switching signals **1102**, **1104** are generated for providing to the first load side converter **116**. Then, the first voltage **1107** at the one or more first output terminals **132** can be obtained.

Similarly, second load side switching signals **1112**, **1114** can be generated for providing to the second load side converter **126** by a comparison of the second modulation wave **1111** with the second positive carrier wave **1113** and a comparison of the second modulation wave **1111** with a second negative carrier wave **1115**. Then, the second voltage **1117** at the one or more second output terminal **134** can be obtained.

As indicated in FIG. 13, the second positive carrier wave **1113** has a phase shift of  $180^\circ$  compared with the first positive carrier wave **1103**. The second negative carrier wave **1115** has a phase shift of  $180^\circ$  compared with the first negative carrier wave **1105**. The second modulation wave **1111** has a phase shift of  $180^\circ$  compared with the first modulation wave **1101**. As a result, the voltage on the winding is a three-level wave which can be obtained by a subtraction of the first voltage **1107** and the second voltage **1117**. According to a simulation result of the embodiment as shown in FIG. 1, for one converter in the topology, the THD in this situation is 0.32%.

Referring to FIG. 14, a waveform diagram illustrating various carrier and modulation waveforms of another carrier-based modulation method used in the power conversion system shown in FIG. 1 in accordance with an illustrative embodiment is shown. Compared with the carrier-based modulation method shown in FIG. 13, there is no difference among the first modulation wave **1201**, the first positive carrier wave **1203**, the first negative carrier wave **1205** and the second modulation wave **1211**. However, a second positive

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carrier wave **1213** has a phase shift of  $90^\circ$  compared with the first positive carrier wave **1203**. A second negative carrier wave **1215** has a phase shift of  $90^\circ$  compared with the first negative carrier wave **1205**.

First load side switching signals **1202**, **1204** and second load side switching signals **1212**, **1214** are generated in the same generating manner as the first load switching signals **1102**, **1104** and second load side switching signals **1112**, **1114** illustrated in FIG. 13. The first load side switching signals **1202**, **1204** are provided to the first load side converter **116** and the second load side switching signals **1212**, **1214** are provided to the second load side converter **126**.

The voltage on the winding is a five-level wave which can be obtained by a subtraction of a first voltage **1207** and a second voltage **1217**. According to a simulation result of the embodiment as shown in FIG. 1, for one converter in the topology, the THD in this situation is 0.95%.

Referring to FIG. 15, a waveform diagram illustrating various carrier and modulation waveforms of another carrier-based modulation method used in the power conversion system shown in FIG. 1 in accordance with an illustrative embodiment is shown. Compared with the carrier-based modulation method shown in FIG. 13, there is no difference among the first modulation wave **1301**, the first positive carrier wave **1303**, the first negative carrier wave **1305** and the second modulation wave **1311**. However, a second positive carrier wave **1313** has a phase shift of  $0^\circ$  compared with the first positive carrier wave **1303**. A second negative carrier wave **1315** has a phase shift of  $0^\circ$  compared with the second negative carrier wave **1305**.

First load side switching signals **1302**, **1304** and second load side switching signals **1312**, **1314** are generated in the same generating manner as the first load switching signals **1102**, **1104** and second load side switching signals **1112**, **1114** illustrated in FIG. 13. The first load side switching signals **1302**, **1304** are provided to the first load side converter **116** and the second load side switching signals **1312**, **1314** are provided to the second load side converter **126**.

The voltage on the winding is a five-level wave which can be obtained by a subtraction of a first voltage **1307** and a second voltage **1317**. According to a simulation result of the embodiment as shown in FIG. 1, for one converter in the topology, the THD in this situation is 1.22%.

From the embodiments shown in FIGS. 13-15, it can be found that the THD is reduced significantly when the phase shift between the first positive carrier wave **1103** and the second positive carrier wave **1113** is  $180^\circ$ .

It is to be understood that a skilled artisan will recognize the interchangeability of various features from different embodiments and that the various features described, as well as other known equivalents for each feature, may be mixed and matched by one of ordinary skill in this art to construct additional systems and techniques in accordance with principles of this disclosure. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

Further, as will be understood by those familiar with the art, the present invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. Accordingly, the disclosures and descriptions herein are intended to be illustrative, but not limiting, of the scope of the invention which is set forth in the following claims.

What is claimed is:

1. A power conversion system, comprising:
  - a first power conversion module coupled with a power source module via one or more first input terminals,

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wherein the first power conversion module is configured to convert a first input power at the one or more first input terminals to a first output power at one or more first output terminals for providing to a load module, the first power conversion module comprising a first source side converter, a first load side converter, and a first DC link coupled between the first source side converter and the first load side converter;

a second power conversion module coupled with the power source module via one or more second input terminals, wherein the second power conversion module is configured to convert a second input power at the one or more second input terminals to a second output power at one or more second output terminals for providing to the load module, the second power conversion module comprising a second source side converter, a second load side converter, and a second DC link coupled between the second source side converter and the second load side converter; and

a controller in electrical communication with the first power conversion module and the second power conversion module, wherein the controller is configured to generate a number of switching signals according to a circuit structure of the power source module or a circuit structure of the load module, wherein the switching signals are provided to the first power conversion module and the second power conversion module to balance a first DC link voltage at the first DC link and a second DC link voltage at the second DC link.

2. The power conversion system of claim 1, wherein: the load module comprises an open-winding transformer configured to provide the first output power and the second output power to a power grid, wherein the open-winding transformer comprises an open-winding primary side and a secondary side, the open-winding primary side is coupled between the one or more first output terminals and the one or more second output terminals; and

the switching signals comprise a number of first and second load side switching signals for providing to the first load side converter and the second load side converter respectively, wherein the first and second load side switching signals are generated according to one or more first load side voltage references and one or more second load side voltage references respectively, wherein each first load side voltage reference and each corresponding second load side voltage reference have the same value with a reverse phase.

3. The power conversion system of claim 1, wherein: the first and second input power are commonly supplied from a non-open-winding generator; and

the switching signals comprise a number of first and second source side switching signals for providing to the first source side converter and the second source side converter respectively, wherein the first and second source side switching signals are generated according to one or more first source side current references and one or more second source side current references respectively, for receiving the same amount of first input active power and second input active power to balance the first DC link voltage and the second DC link voltage.

4. The power conversion system of claim 1, wherein: the first input power is supplied from a first power source of the power source module, the second input power is supplied from a second power source of the power



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source module, and the first power source and the second power source are separately arranged from each other; and

the switching signals comprise a number of first and second source side switching signals for providing to the first source side converter and the second source side converter respectively, wherein the first and second source side switching signals are generated according to a first source side power reference and a second source side power reference respectively, for receiving the same amount of first input power and second input power to balance the first DC link voltage and the second DC link voltage.

5. The power conversion system of claim 1, wherein: the first input power and the second input power are commonly supplied from an open-winding generator; and the switching signals comprise a number of first and second source side switching signals for providing to the first source side converter and the second source side converter respectively, wherein the first and second source side switching signals are generated according to one or more first source side voltage references and one or more second source side voltage references respectively, for receiving the same amount of first input active power and second input active power to balance the first DC link voltage and the second DC link voltage, wherein a source side dynamic coefficient is set between each of the one or more first source side voltage references and each of the corresponding one or more second source side voltage references.

6. The power conversion system of claim 5, wherein the source side dynamic coefficient is calculated based at least in part on a ratio or a difference between a first feedback DC link voltage at the first DC link and a second feedback DC link voltage at the second DC link.

7. The power conversion system of claim 1, wherein: the power source module comprises an open-winding transformer configured to receive the first input power and the second input power from a power grid, the open-winding transformer comprises a primary side and an open-winding secondary side, wherein the open-winding secondary side is coupled between the one or more first input terminals and the one or more second input terminals; and

the switching signals comprise a number of first and second source side signals for providing to the first source side converter and the second source side converter respectively, wherein the first and second source side signals are generated according to one or more first source side voltage references and one or more second source side voltage references respectively, wherein each of the first source side voltage references and each of the corresponding second source side voltage references have the same value with a reverse phase.

8. The power conversion system of claim 1, wherein: the first output power and the second output power are commonly provided to a DC load; and

the switching signals comprise a number of first and second load side switching signals for providing to the first load side converter and the second load side converter respectively, wherein the first and second load side switching signals are generated according to a first load side power reference and a second load side power reference to provide the same amount of first output power and second output power, to balance the first DC link voltage and the second DC link voltage.

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9. The power conversion system of claim 1, wherein: the first output power and the second output power are commonly provided to an open-winding motor; and the switching signals comprise a number of first and second load side switching signals generated according to one or more first load side voltage references and one or more second load side voltage references respectively, for providing the same amount of first output active power and second output active power to the motor to balance the first DC voltage and the second DC voltage, wherein a load side dynamic coefficient is set between each of the one or more first source side voltage references and each of the corresponding one or more second source side voltage references.

10. The power conversion system of claim 9, wherein the load side dynamic coefficient is calculated based at least in part on a ratio or a difference between a first feedback DC link voltage at the first DC link and a second feedback DC link voltage at the second DC link.

11. The power conversion system of claim 1, wherein: the load module comprises a transformer for providing an output power obtained from the first output power and the second output power to a power grid; and the switching signals comprise a number of first load side switching signals generated by comparing one or more first load side voltage references with one or more first carrier waves and a number of second load side switching signals generated by comparing one or more second load side voltage references with one or more second carrier waves, wherein a phase shift is set between each first carrier wave and each corresponding second carrier wave.

12. A method for controlling a power conversion system, the method comprising: generating a number of switching signals according to a circuit structure of a power source module or a circuit structure of a load module; and providing the number of switching signals to a first power conversion module and a second power conversion module to balance a first DC link voltage at a first DC link and a second DC link voltage at a second DC link.

13. The method of claim 12, comprising generating a number of first and second load side switching signals according to one or more first load side voltage references and one or more second load side voltage references when the load module comprises an open-winding transformer, wherein each of the first load side voltage references and each of the corresponding second load side voltage references have the same value with a reverse phase.

14. The method of claim 12, comprising generating a number of source side switching signals according to one or more first source side current references and one or more second source side current references to receive the same amount of first input active power and second input active power when the power source module is a non-open-winding generator.

15. The method of claim 12, comprising generating a number of source side switching signals according to one or more first source side voltage references and one or more second source side voltage references to receive the same amount of first input power and second input power when the power source module is an open-winding generator, wherein a source side dynamic coefficient is set between each of the one or more first source side voltage references and each of the corresponding second source side voltage references.

16. The method of claim 15, comprising calculating the source side dynamic coefficient based at least in part on a ratio

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or a difference between a first feedback DC link voltage at the first DC link and a second feedback DC link voltage at the second DC link.

17. The method of claim 12, comprising generating a number of first and second source side switching signals according to one or more first source side voltage references and one or more second source side voltage references when the power source module comprises an open-winding transformer, wherein each of the first source side voltage references and each of the corresponding second source side voltage references have the same value with a reverse phase.

18. The method of claim 12, comprising generating a number of load side switching signals according to one or more first load side current references and one or more second load side current references to provide the same amount of first output active power and second output active power when the load module is a non-open-winding motor.

19. The method of claim 12, comprising generating a number of load side switching signals according to one or more first load side voltage references and one or more second load side voltage references to provide the same amount of first output active power and second output active power when the load module is an open-winding motor, wherein a load side dynamic coefficient is set between each of the one or more first load side voltage references and each of the corresponding second load side voltage references.

20. A wind power conversion system, comprising:

a wind generator for providing a first input power at one or more first input terminals and a second input power at one or more second input terminals;

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a first power conversion module coupled with the wind generator via the one or more first input terminals, wherein the first power conversion module is configured to convert the first input power to a first output power at one or more first output terminals for providing to a power grid, the first power conversion module comprising a first rectifier, a first inverter, and a first DC link coupled between the first rectifier and the first inverter;

a second power conversion module coupled with the wind generator via the one or more second input terminals, wherein the second power conversion module is configured to convert the second input power to a second output power at one or more second output terminals for providing to a load module, the second power conversion module comprising a second rectifier, a second inverter, and a second DC link coupled between the second rectifier and the second inverter; and

a controller in electrical communication with the first power conversion module and the second power conversion module, wherein the controller is configured to generate a number of source side switching signals according to a winding-structure of the generator for providing to the first rectifier and the second rectifier, to reduce the voltage difference between a first DC link voltage at the first DC link and a second DC link voltage at the second DC link.

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